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Prediction of Flexural Behavior of Woven Reinforced for Concrete Reinforcement

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Abstract. Plain concrete possesses very low tensile strength, limited ductility and little resistance to cracking. Fibers glass-reinforced concrete supposed to improve the strain properties well as crack resistance, ductility, as flexural strength and toughness. This paper aims to predict the flexural behavior of fiber-glass reinforced concrete and optimize the beam design by applying woven layer in M35 grade concrete using finite element method. The several techniques were implemented to study flexural performance, woven position on bottom, middle and upper surface and several woven thickness layers employed to investigate flexural performance such as 5, 10, 20, 30, 40 and 50 mm for beam size of 100 × 100 × 500 mm. It found that the flexural strength increased by positioned the woven on the bottom side and it given the improvement in designing when the layer thickness of fiber varied. It is because the fiber usually reduces the brittleness of concrete by providing post cracking ductility and increase toughness. The difference flexural strength between 50mm and 40mm thickness of fiberglass is about 1.29%.

1. Introduction

Fiber is commonly used to improve the material's toughness and elasticity because cracking of cementitious composites affects the durability of concrete in the marine structure. However, the fiber distribution is strongly influenced by various factors, such as fiber characteristic, matrix features and placing method. Some of the fibers produce greater concrete impact, which is abrasion and shatter resistance [1,2]. Fiber also has high strength and large elongation. The fibre-reinforced concrete had been used in the marine structure to improve the strength of the concrete and also prevent the construction from the corrosion and improve the resistance to shattering forces caused by the sea wave. It is because, fiber helps to improve toughness with additional property enhancement like pre-crack tensile strength, post-peak ductility performance, fatigue and impact strength [3,4].

Fiber-reinforced concrete was successfully used in a variety of engineering applications, because of its satisfactory and outstanding performance in the industry and construction field. However, most of the engineers and researchers have thought that how and why the fibers perform so successfully. So, to recognize the usage of fibers in concrete, most of the researches were done on behavior of fiber-reinforced concrete. Fiber Reinforced Concrete is a popular structural material developed by James



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Hardie in the early 1980s. Fiber concrete is a strong, durable material used in a number of internal and external construction applications, including for marine structure. The fiber reinforced concrete is a precisely formulated mix of cellulose fiber, water, sand and cement. The previous researcher found that the adding fiber increased cemented soil's peak and residual shear strength and bound to more ductile its brittle behavior. Besides, energy absorption increased by 20% - 50% by adding the fiber. Fiber was more effective at 70 percent relative density on the shear strength parameter [5]. Another researcher also reported that the studies and analysis about the marine structural failures are due to lack of operational consideration, incomplete evaluation of structural elements and incorrect use of calculation methods [6].

In flexural performance, fiber reinforced concrete leads to recommended in given the significantly increasing on axial load and mixed with other addition as the concrete core; however, it is commonly applied that unlike as reinforced concrete beams, on the peak of deflection exhibit to brittle manner as a result [7]. Some observed when removed the confined tube, the plain concrete as cores developed produces tend to larger flexural cracks at the center of the columns or even damaged to side sample then distributed along with the columns [8]. Furthermore, several significant founding when considering fiber reinforced concrete columns used in a practical project, a small amount of steels reinforcement was adding to counter brittle failure occur in the column [9]. Other researcher-developed fiber reinforced concrete piles in the construction of the Route 40 highway bridge over the Nottoway River in the United States [10].

Efficiency material design required entirely in reducing cost experimental and time constrain during research. Technically which optimizing the material design by using simulation will reduce materials supply for production cost. From previous researchers have been reported that morphologies analysis bring materials synergy effect on mechanical performance [11] and accurately prediction material design [12, 13]. The model proposed characteristic structure of fiber orientation that effect in mechanical performance due to lack of fiber-reinforced distribution contribute to inhomogeneity stress distribution.

The objective of this work is to perform a study on the use of fibrous glass woven as reinforcement of concrete and layered in fiber reinforced composites as the concrete reinforcement. The fiberglass woven is varied in position and number from the bottom until top of beam surface in structure designing. Uniaxial compression and third-point bending tests were conducted to assess the composite beams as axial and flexural structural members. The effects of fiberglass woven inclusion on the compressive and flexural performance of the composite beams were investigated. In addition, the ultimate flexural and compressive strength of fiberglass woven concrete was predicted using finite element models and validated with the experimental and theoretical results.

2. Methodology

In this flexural behavior study, the fiber-reinforced concrete was using fiber glass woven fabric from previous researcher [14], while plain concrete was employed M35 grade concrete that provide by ANSYS Workbench. A model of the fiber-reinforced composites for concrete reinforcement constructed by using finite element method software.

2.1. Sample Preparation

The sample testing utilizes preferred sizes of 100 mm× 100 mm×500 mm based on ASTM C1609 standard. Early-stage of study, 5 mm of the thickness of woven fiberglass was used to investigate the significant effect on flexural performance and compressive strength. The several techniques was implemented in this study that positioned on the bottom, middle and upper surface of the beam. In a further study, the varied thickness was investigated in the beams from the 10 mm until to 50mm layer thickness of woven fiberglass used in this research. The layer thickness of fiber was added in bottom of the concrete beam to increase their strength. The example of the position of the layer thickness of fiberglass can be seen in Figure 1.

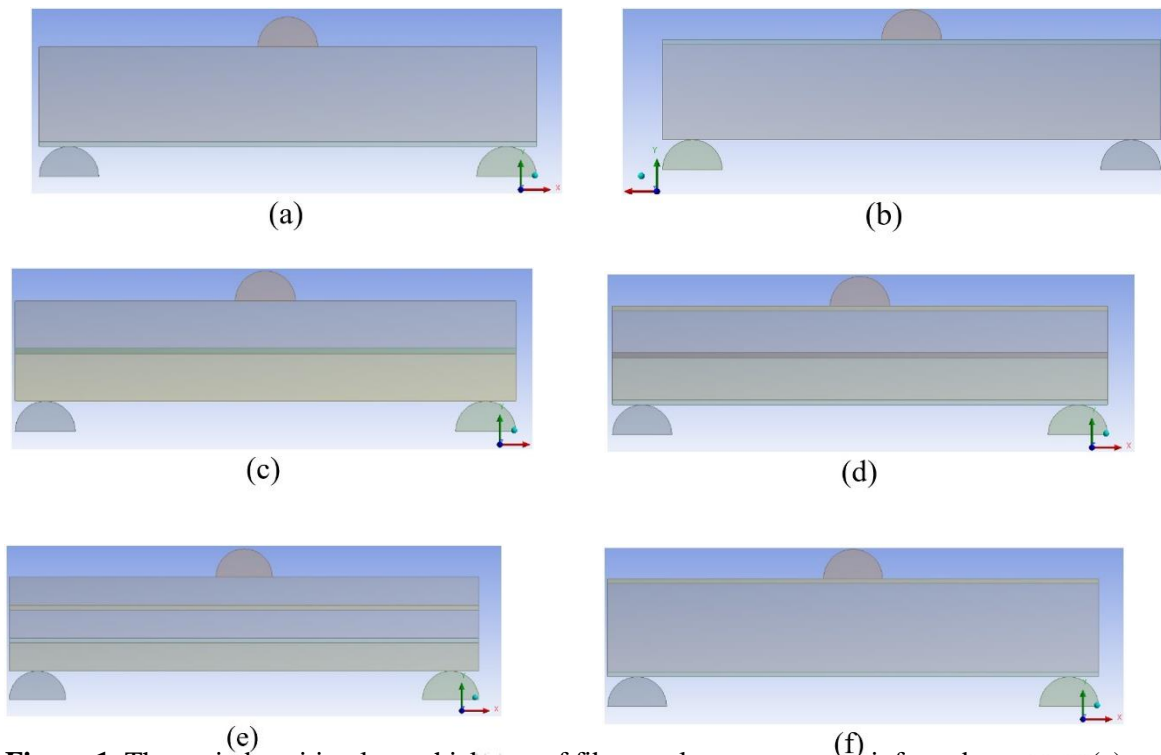


Figure 1. The varied position layer thickness of fibrous glass woven as reinforced concrete; (a) Bottom, (b) Top, (c) Middle (d) 3Plies (e) 2Plies (f) Top&Bottom

2.2. Meshing

The meshing chosen was Hexahedron for the beam body due to symmetry in cubical shape and it was simple to discretization, while the size was 10mm based on grid independence study as present in Figure 2. The total number for both nodes and elements implemented in the beams were 6996 and 5510, respectively. The grid independence study was simulated on plain concrete of M35 grade in three-points bending flexural performance. The flexural strength state that insignificant change or fluctuate condition on the performance. Furthermore, three-points bending flexural support was using semi-spherical to reduce element number and it constructed using tetrahedron shape element.

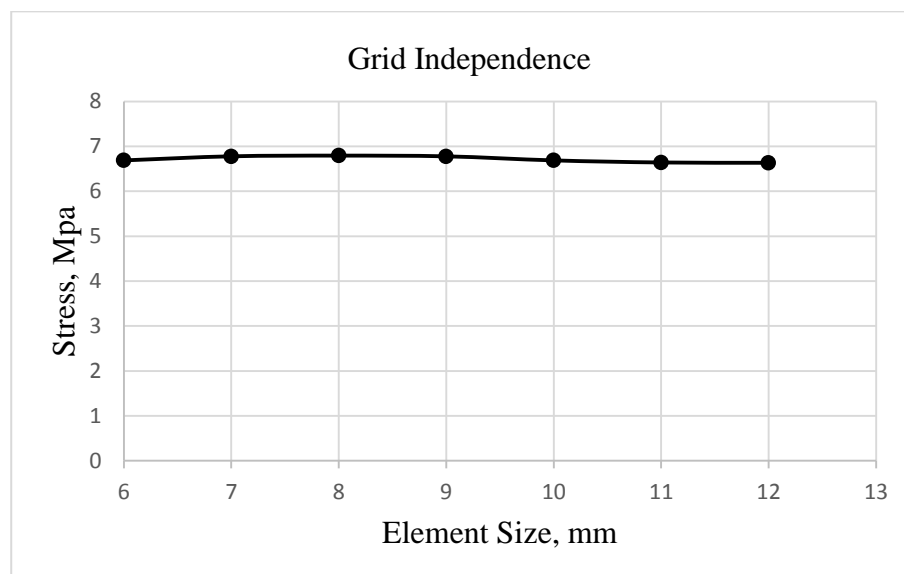


Figure 2. Grid independence study for flexural model

2.3. Loading and Boundary Condition

The reinforced concrete beam used in finite element analysis is a simply supported beam according to the experimental configuration. Therefore, it is necessary to define the boundary condition that supports the loads applied to the beam explicitly in this finite element model. The left and right end of the bottom concrete beam it was be fixed support. The force 9000N was applied on center top of the concrete beam as a three-point bending load.

2.4. Validation.

The validation of the research implement by using the three-point bending theoretical for the flexural strength. The flexural three-point bending test provides values for the elasticity module in bending, such as flexural stress, flexural strain and the material's flexural stress-strain. The flexural stress (δ_f) is a stress caused by the bending moment. It can be calculated on any point on the deflection curve by using Eq. (1) below:

$$\delta_f = \frac{3FL}{2bd^2} \quad (1)$$

while the error between two different results from the Finite Element Analysis and theoretical can be calculated by using Equation 2 below:

$$\text{Error} = ((\text{Experiment} - \text{Numerical}) / \text{Experiment}) \times 100$$

In addition, the validation of the M35 Grade concrete beam can be compare to the previous study [15]. Based on previous researcher reported that flexural tensile strength for M35 grade concrete was determined as $1.2f_c^{0.5}$ it should be around 7 MPa of strength. It was observed that the flexural strength of the M35 concrete beam error earned by using theoretical and previous study presented 0.7936% and 4.1595% error, respectively as shown in Table 1.

Table 1. Comparison of Flexural Strength of M35 grade concrete beam by using theoretical and previous research to current research.

$\sigma = 1.2 \times \sqrt{f'_c}$	Flexural Strength (MPa)	ANSYS Output (MPa)	Error
	7.09929574	6.804	4.1595
$\sigma = \frac{3FL}{2wd^2}$	6.75	6.804	0.7937

3. Results and Discussions

The individual result of the beam by the varied position of 5 mm thickness of woven fiberglass presented in Figure 3, where the position on bottom lead in flexural performance. It due to the bottom surface expressed as tensile load along axial while the top surface absorbs the compressive stress during the flexural test. The effective layer on the bottom can counter the concrete weakness in tensile resistance by large elongation of fiber to avoid pre-crack in the concrete. It proofs by the results that show in Figure 4, where higher flexural resistance of the beam giving by bottom position at 7.2 MPa (Figure 4(b)), while Figure 4(a) perform at 6.8 MPa. This comparison behavior giving an idea that the bottom side is a paramount part to be protected during the flexural condition. In further observation, the layer exhibited behavior on compressive testing which insignificant effect on compressive resistance was demonstrated such shown in Figure 5. Figure 5(b) demonstrate that the layer was not play important role in the upright position during compressive work by performing slightly lower compare to plain concrete in Figure 5(a).

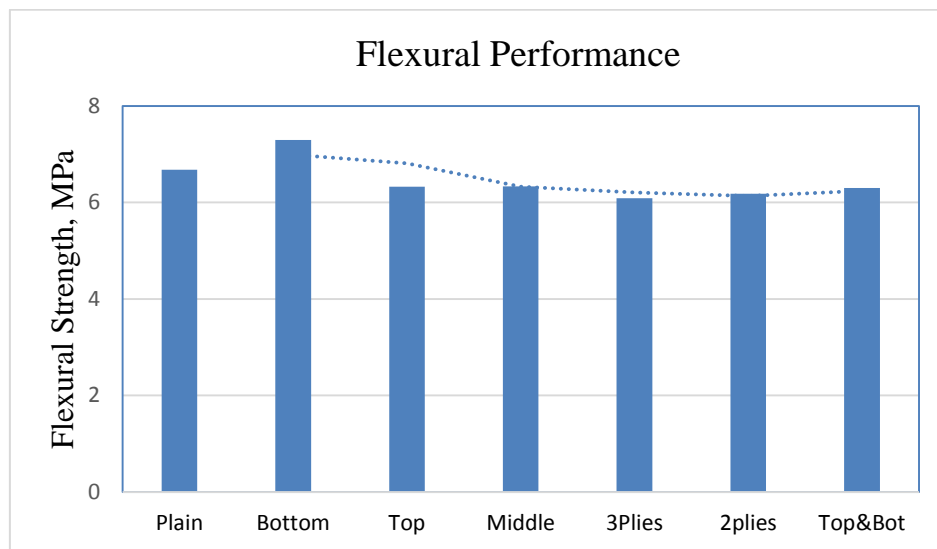


Figure 3. Comparison of flexural performance by varied position

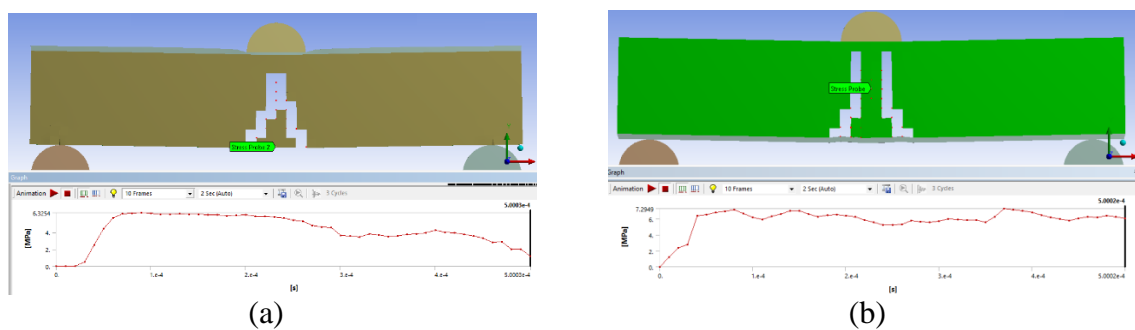


Figure 4. Comparison flexural performance results; (a) Top position, (b) Bottom position

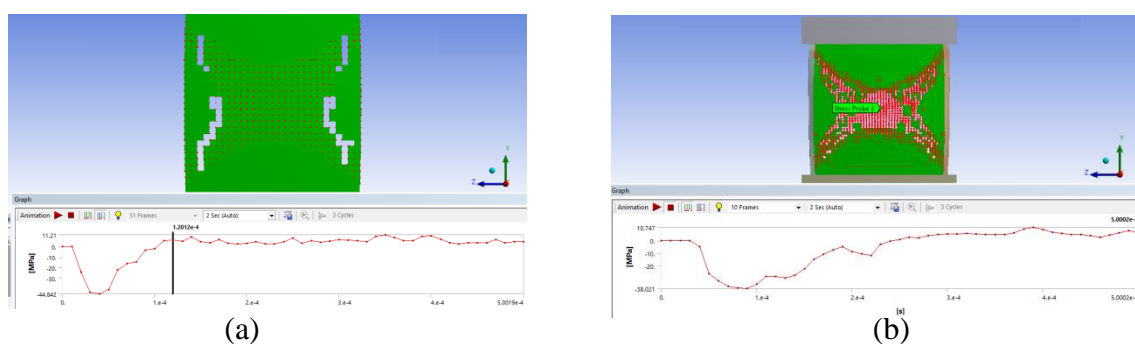


Figure 5. Comparison of compressive strength; (a) plain concrete of M35 grade, (b) concrete with coupling by layer.

The simulation result of the fiber-reinforced concrete by combination layer thickness was presented and discussed with the reference to the aim of the study which was to optimize the layer thickness of glass fiber in M35 grade concrete in increasing flexural strength of concrete beam in this chapter. The flexural strength of M35 concrete beam with different thickness of fiberglass was determined from 10mm until 50mm layer thickness of fiber. The result of this simulation as shown in Table 2.

At the strain 0.05, the maximum stress of the plain concrete beam has 6.804MPa occurred. Besides, the maximum stress of the concrete with 10mm layer thickness of fiberglass is 8.635MPa and strain

0.01. The ultimate tensile strength of the concrete beam was increased when the 10mm thickness of fiber was added. It has been compared with the plain concrete beams. The strength concrete beam increased by 18.65% when 10mm of fiberglass was added as shown in Figure 6. When 30mm thickness of fiberglass was added, the highest tensile strain is 0.0598 at 14.8298 MPa of flexural strength. It means the strength of the concrete beam increased by 54.12% as shown in Figure 7. In this study found that the flexural strength increased when the layer thickness of woven fiber increased. It is because the fiber usually reduces the brittleness of concrete by providing post cracking ductility and increase toughness. The difference flexural strength between 50mm and 40mm thickness of fiberglass is about 1.29% as shown in Figure 8.

Table 2. The flexural strength of M35 Concrete beam by varied layer thickness.

Thickness of Fiber (mm)	Flexural Strength (MPa)
0	6.8049
10	8.36464
20	9.0564
30	14.8298
40	19.8785
50	20.656

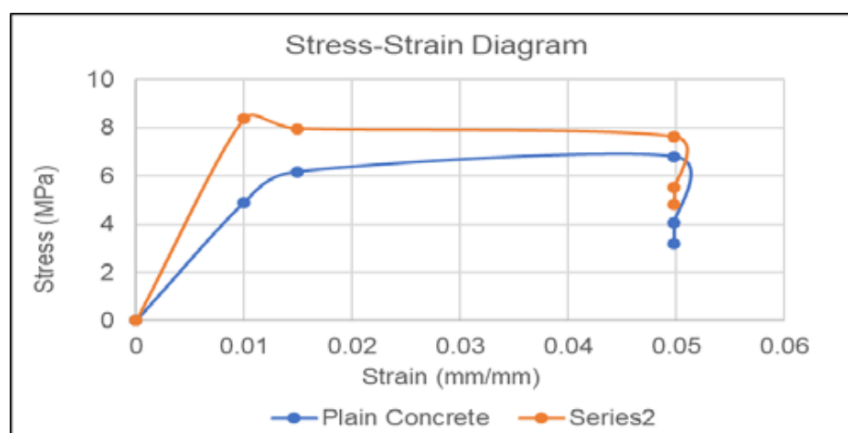


Figure 6. Stress-Strain diagram of flexural strength of concrete with 10 mm thickness of the layer.

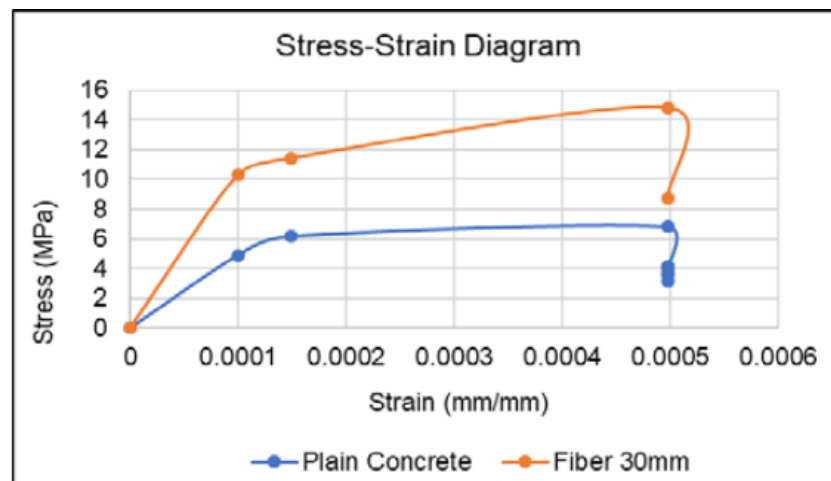


Figure 7. Stress-Strain Diagram for the concrete beam with 30mm layer thickness.

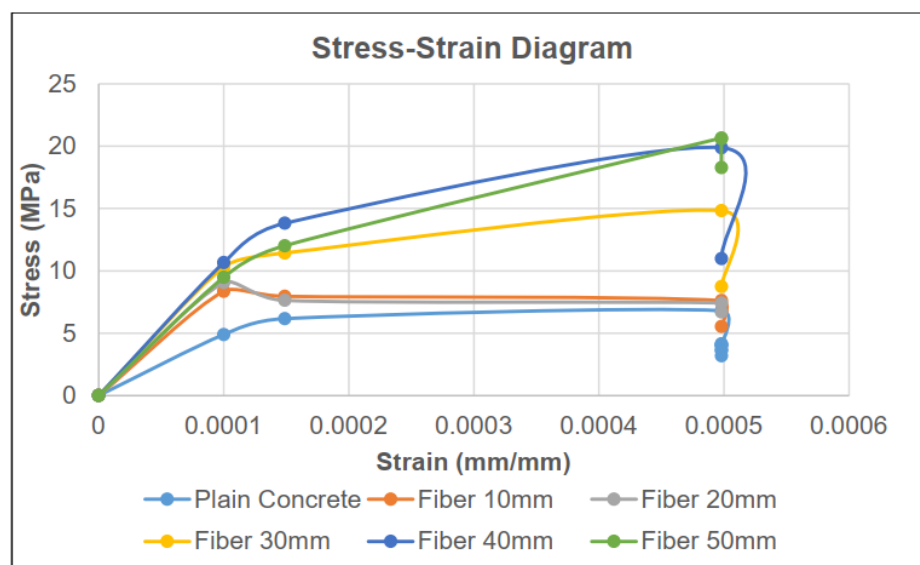


Figure 8. Stress-Strain diagram of flexural performance by varied layer thickness.

4. Conclusions

To achieve a sustainable beam structure, the performance in flexural condition can be predicted by using fiber-reinforced composite for concrete reinforcement. The simulation results with respect to axial stress-strain behavior, structure ductility, ultimate compressive strength were successfully predicted. The woven layer under flexural testing effectively increasing the beam performance around 5.8% that demonstrated by layer on the bottom position. However, the compressive strength no not much help in the upright position due to weak in stiffness of fiber-reinforced composite. This study giving an idea to improve flexural performance by optimizing the layer thickness which positioned on bottom condition. The flexural strength of concrete beam increased by adding the more layer thickness of fiberglass. By comparing to plain concrete, woven fiber-reinforced composite has produced higher flexural strength, ductility and toughness. The improvement has successfully shown by increasing the layer thickness from the bottom to upward of the beam. In addition, different layer thickness on the bottom of the concrete beam used to achieve a solution to increase flexural performance.

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